Biomass energy with geological sequestration of CO_2: Two for the price of one?

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Stabilizing atmospheric CO_2 concentration at a level sufficient to prevent dangerous interference with natural systems—the agreed goal of the Framework Convention on Climate Change—presents a fundamental challenge to industrial society. Limiting the climate forcing from all greenhouse gases to a degree equivalent to a doubling of pre-industrial CO_2 concentrations will require decreases in CO_2 emissions by as much as 50% below business as usual projections within 50 years[1]. Biomass has long been investigated both as a (nearly) CO_2 neutral substitute for fossil fuels and as a means of offsetting industrial emissions by sequestering carbon in terrestrial ecosystems [2]. More recently the possibility of using fossil fuels without CO_2 emissions by capturing CO_2 and sequestering it in geological formations has emerged as an important means of mitigating emissions because of its compatibility with existing fossil fuel infrastructures[3, 4]. Here we analyze the economics of combining the two, of using biomass with carbon capture and sequestration (CCS).

Biomass offers multiple CO2 mitigation options because it links the biological carbon cycle with industrial energy systems. These options can be divided into four general categories [5]: in situ sequestration through reforestation and conservation; substitution of biomass for fossil fuels; remote biomass sequestration by harvest and burial; and biomass energy substitution with CCS, the focus of this paper. The utilization of biomass energy products with CCS offers the largest potential impact on atmospheric CO2 concentrations per unit of land due to the double benefit of reducing emissions from energy production and effectively removing carbon from the carbon cycle via sequestration in geological formations. This double benefit cannot be realized with any of the other strategies.

While biomass energy with CCS is largely unexplored, several factors make it an attractive option to pursue as one component within a portfolio of carbon mitigation strategies. First, the system would efficiently utilize limited land and water resources by capitalizing on the potential double benefit of providing low carbon intensity energy products and removing CO2 from the carbon. This efficiency is critical given the diverse competition for productive acreage. Second, the net reduction in atmospheric CO2 from a biomass energy system with CCS could provide a mechanism to offset emissions from other sources. Top-down economic estimates of the cost of stabilizing atmospheric CO2 concentrations at an effective doubling of pre-industrial levels show marginal carbon prices rising above 1000 dollars per ton carbon ($/tC) mitigated [6]. These high costs are a result of specific emissions sources, particularly in the transportation sector, that are expected to be difficult to mitigate directly. In contrast, conservative initial estimates suggest that biomass energy with sequestration would have mitigation costs below 200 $/tC. If the atmospheric reductions from this system were credited to sources with only high cost mitigation options, than the cost of mitigation would essentially be capped at 200 $/tC. Alternatively, if a carbon tax or shadow price system were established, biomass energy from a facility with sequestration would become the lowest cost option at shadow prices below 200 $/tC. Finally, all of the components necessary for this system have already been developed and are functioning in large-scale facilities. For example, biomass gasifiers, shift reactors, CCS systems, and integrated combined cycle gas turbines are all in development or commercial use. While it is clear that some modification of the components will be necessary, for example to convert the gas turbine to use the hydrogen gas exiting the CCS system, these modifications generally should not require any major technological breakthroughs.

We present results from a simplified model comparing the cost of CO2 mitigation from a biomass integrated gasification combined cycle system with CCS to other mitigation options in the electric sector.

The model assumes a conservative estimate of biomass supply costs and incorporates estimates of system component costs and performance from published works and existing systems in a “bottom-up” engineering-economic model. An example of this analysis is shown in Figure 1. We will also look beyond the electric sector and compare biomass electricity generation with sequestration to other options for biomass based CO2 mitigation, such as the production of liquid transportation fuels, and explore how CCS might be combined with these systems.

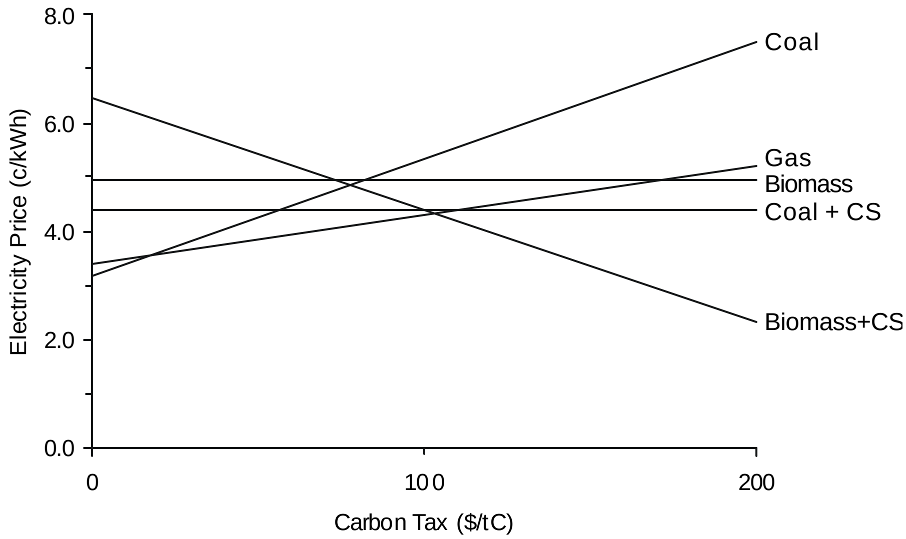

Figure 1. Cost of electricity as a function of carbon tax. The figure assumes a fuel cost of 1, 3 and 3.5 $/GJ for coal, biomass and natural gas respectively, and uses conservative estimates for the cost and performance of carbon sequestration technologies. Contrary to many studies we assume that biomass fired electric power plants will be large, above ~100 MWe, and that at this size the cost and performance of coal and biomass fired facilities are similar. Below about 50 $/tC switching to natural gas provides the least cost carbon mitigation; in the range 50 to 150 $/tC the various options have similar prices and the question of which is cheapest hangs on the details of the cost assumptions; above ~150 $/tC biomass, with carbon sequestration will provide the lowest cost electricity for almost any plausible assumptions about cost of fuel and generation technology. A similar figure can be constructed for the price of hydrogen as a function of carbon price.

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